Changing Economics and Impact of Recent Developments on Nuclear Power and Reactor Decommissioning in the United States -14423

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ABSTRACT

Recently a dramatic change is taking place in the commercial nuclear power industry and a re-examination of economic viability of reactors, especially the older reactors, is in progress. In the last year, four reactors have been shutdown and more are likely to follow. Two main factors that are impacting the future of nuclear power as well as decommissioning of reactors in the United States include post-Fukushima actions for the operating reactors and the changing economics for electricity generation. As nnatural gas prices in the United States have fallen dramatically, it is becoming the fuel of choice for many electric utilities with a diversified generation portfolio. The decommissioning scene in the United States is changing as the cost of staying in operation for the aging reactors becomes non-competitive.

This paper discusses the impact of changing energy economics in the United States on the role of the nuclear power in the country. It provides a status update on the reactor decommissioning scene. It analyzes the current trends and provides decommissioning projections for a postulated scenario to illustrate the upcoming growth in decommissioning.

INTRODUCTION

Only a few years ago, almost all reactors were renewing their licenses for continued operation after their current licenses are set to expire. However, recently a more dramatic change is taking place in the industry and a re-examination of economic viability of reactors, especially the older reactors, is in progress at several stations.

The Kewaunee power reactor, a 556 MWe PWR had its license renewal approved on February 24, 2011; however, on October 22, 2012, Dominion Resources Inc, the owner of the plant, publicly announced its impending shutdown due to economic reasons and the plant was shutdown on May 7, 2013. On February 5, 2013, Duke Energy announced the closure of the Crystal River nuclear plant. The 860 MWe PWR entered outage in September 2009 for steam generator replacement and for power uprate but ran into a number of problems and could not restart in April 2011 as originally scheduled. Duke Energy which took over Progress Energy and the Crystal River Plant announced permanent shutdown of the plant in February 2013. The Oyster Creek reactor, a 636 MWe BWR, which is licensed to operate until 2029 (license renewed in 2009), is

[1]The views expressed in this paper are those of the author and do not necessarily reflect the views of his employer or the clients.

scheduled to be permanently shut down by 2019, ten years earlier than the licensed period. On June 7, 2013, Southern California Edison announced that it would permanently retire SONGS Units 2 and 3 ending attempts at steam generator replacements and to re-start the units citing cost, economic factors, and post-Fukushima requirements. Unit 1 was shut down earlier and entered decommissioning in 1992.

Two main factors are impacting the future of commercial nuclear power and decommissioning of reactors in the United States. First, the follow up actions resulting from NRC's post-Fukushima Near Term Task Force recommendations are requiring industry to make provisions and changes for Beyond-Design-Basis External Events. For the older reactors, the industry is re-examining whether continued expenditures to retrofit the reactors for major systems or components are cost-effective.

Second, the Natural gas prices in the United States have fallen dramatically with shale gas rapidly increasing its share in the total natural gas production. The commercial gas prices have fallen to about one fifth of what they were five years ago. Essentially, the natural gas prices are currently at a level what they were in 1995. In a climate of such a dramatic change in the energy landscape, natural gas is becoming the fuel of choice for many electric utilities with a diversified generation portfolio.

Above factors, combined with the fact that the capital costs for building a nuclear reactor keep escalating and no additional federal loan guarantees are likely, have further diminished the prospects of reviving the nuclear renaissance. Added to all this is also the fact of closure of the Yucca Mountain repository project where the funding was zeroed out in the fiscal year 2011 DOE budget. Currently, there is no national path to disposal for the used nuclear fuel. The lack of disposal facilities for used nuclear fuel also impacts the decommissioning sites as dry storage facilities will remain at most of the decommissioned reactor sites for a long time.

This paper discusses the impact of changing energy economics in the United States on the role of nuclear power in the country's mix of energy sources. It focuses on the commercial power reactors and provides a status update on the decommissioning scene in the United States and how it is changing as the cost of staying in operation for the aging reactors becomes non-competitive. It also analyzes the use of the SAFSTOR option which is favored by the recently shutdown reactors and presents a case that choosing the long-term storage for a reactor site may not be the best option as compared to successful immediate dismantlement and decommissioning of the retired reactors. Finally, the paper provides decommissioning projections for a postulated scenario to illustrate the upcoming growth in reactor decommissioning.

ENERGY DEMAND AND ROLE OF NUCLEAR POWER

In the World Energy Outlook (WEO) 2013, released in November 2013 [1] by the International Energy Agency (IEA), the global energy demand for the central scenario increases by one-third from 2011 to 2035. The global energy demand is primarily attributed to emerging economies as they account for more than 90% of net energy demand growth to 2035 led by China in this decade but shifting towards India and Southeast Asia after 2025. Overall, while the demand grows for all forms of energy, the share of fossil fuels in the world's energy mix is expected to fall from 82% to 76% in 2035. Low-carbon energy sources (renewable sources including hydro, wind, solar, other; and nuclear) are expected to meet around 40% of the growth in primary energy demand. However, it should be noted that in the WEO 2012, the IEA had adjusted the projections for global nuclear generating capacity downwards which is expected to reach some 580 GWe worldwide in 2035 and which was 10% less than the IEA forecast a year earlier.

The Word Nuclear Association (WNA) data from November 2013 [2] shows that over 430 commercial nuclear power reactors operating in 31 countries have a combined capacity of 370 GWe and they provide about 11% of the world's electricity. In the US, The 100 reactors (as of 2013) make it the largest fleet of commercial power reactors in one country and nuclear provides about 19 % of the electricity generation in the US. Worldwide, over 60 reactors are under construction in 13 countries, with major construction activity in China, South Korea, Russia, and India.

The growth in electrify demand in the United States has slowed and the electricity generation capacity has continued to increase fueled by natural gas. In the Annual Energy Outlook (AEO) 2013 issued in April 2013 [3], the Energy Information Agency (EIA) acknowledges a revised outlook for the production of gas to reflect the impact of shale gas production and lower natural gas prices. This in turn has spurred and is expected to spur the use of natural gas for the electric power generation in the country.

CHANGING ENERGY ECONOMICS

The Impact of Cheaper Natural Gas

Natural gas prices have fallen dramatically in the United States and a whole new industry of hydrofracturing to extract natural gas is expanding. In the past five years the commercial gas prices have fallen to about one fifth of what they were a few years ago. Essentially, the natural gas prices are currently at a level what they were in 1995 after peaking in the years 2001, 2006, and 2008. As Figure 1 shows even in the EIA projections to 2040, the rise in natural gas prices is expected to be gradual and mostly related to increase in production costs.

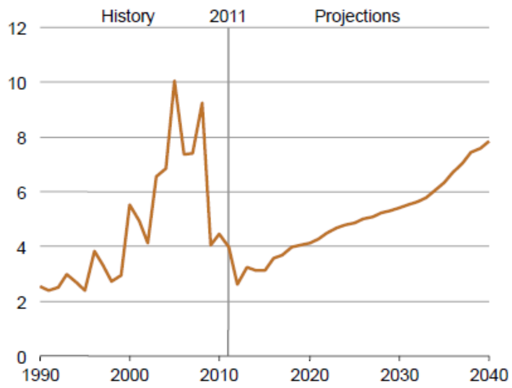

Figure 1: Natural Gas Prices (Annual average Henry Hub spot natural gas prices, 1990-2040 (2011 dollars per million BTU)
Source: EIA-0383(2013)

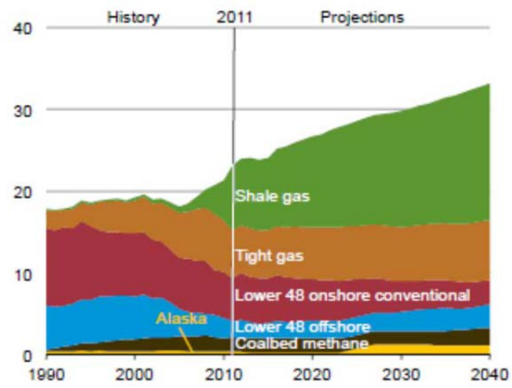

Figure 2: Natural Gas Production by Source, 1990-2040 (trillion cubic feet)
Source: EIA-0383(2013)

The large increase in gas production is led by a boom in the shale gas production as shown in Figure 2. Shale gas provides the largest source of growth in U.S. natural gas supply, growing by 113 percent from 2011 to 2040 and contributing the largest portion of the overall total gas production which itself increases 44 percent from 2011 through 2040. Gas production and the demand mismatch at the present time has resulted in a situation where United States is becoming a net exporter of natural gas.

In a climate of such a dramatic change in the energy economics, natural gas is becoming the fuel of choice for many electric utilities. What makes the impact of cheaper gas more pronounced in cost comparison is the fact that for a natural gas plant fuel accounts for nearly 85% of the cost of electric power production, with remaining being the O&M costs. This is as compared to a nuclear plant where fuel is only about 30% of the production costs with O&M accounting for about 70% of the production cost. (However, it should be recognized that this comparison does not take into account the capital costs.) In essence, the reductions in natural gas prices lead to a disproportionate lowering of the overall cost of electricity production.

The projected share of the nuclear growth is directly impacted by the ample (surplus) supply of natural gas. This is borne by the projections shown in Figure 3 (which has been adapted from EIA data for this purpose) where the growth of electricity production from natural gas is compared to the electricity production from nuclear. The nuclear power plant capacity grows only slowly as depicted in Figure 4 and it is primarily through the uprates and some new build.

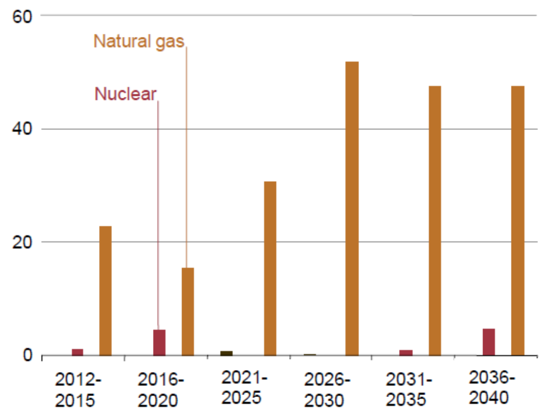

Figure 3: Electricity Generation Capacity Additions 2012-2040 (GWe): Comparison Nuclear and Natural Gas
Source: Adapted from EIA-0383(2013)

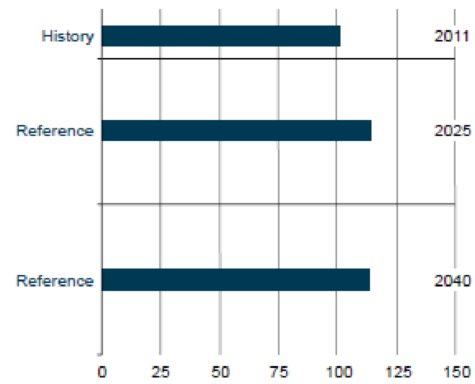

Figure 4: US Nuclear Generating Capacity at Year 2011, 2025 and 2040 for Reference Growth Case (in GWe)
Source: Adapted from EIA-0383(2013)

In the detailed data available from the EIA, the nuclear power capacity increases from 101.1 GWe in 2011 to a high of 114.1 GWe in 2025, before declining to 108.5 GWe in 2036 largely as a result of plant retirements. New additions in the later years of the projection bring nuclear capacity back up to 113.1 GWe in 2040. The data already takes into account the four advanced reactors, under construction (two at Vogtle site and two at VC Summer site) which are assumed to be brought online by 2020.

From the above data and discussion it is clear that with abundant gas reserves and dramatically lower costs (and even with gradual increase), electricity generation with natural gas will be the preferred choice and it will directly impact the role of nuclear power in the United States. In addition, the nuclear power reactors are expensive to build with costs ranging generally from 6 to 8 billion dollars (for example, the current estimates for the two reactors at Vogtle site are $14 billion). Thus, power reactor development requires long term stability in production, fuel, and other costs for the lifecycle costs to be competitive.

Post-Fukushima Actions for Nuclear Power Plants

Only a few years ago, nuclear industry was thought to be in the early stages of a “renaissance”, and it had been estimated that anywhere from 60 to 130 new power reactors might be built worldwide over the next twenty years. In the US, almost all reactors were renewing their licenses for continued operation after their current licenses are set to expire. In addition, several applications had been filed with the NRC as the first step for the construction of new power reactors. Then, the Fukushima accident happened. The net effect of Fukushima accident on nuclear renaissance has been to slow it down worldwide. In the United States, the new build in the next two decades may be limited to only the existing projects to build the four new reactors which are already in some stages of construction.

The Fukushima accident on March 11, 2011 was caused by the combination of a magnitude 9 earthquake and the related big tsunami off the eastern coast of Japan. It has led to a global re-examination of the design basis for nuclear power plants for natural events. While the Fukushima reactors and the site have been stabilized, cleanup of contaminated water from cooling of the reactors and the Spent Nuclear Fuel (SNF) pools continues and decommissioning of the site will take decades. The impacts of the accident continue to be assessed from a technical perspective; however a number of actions have already been taken in most countries. The existing nuclear power plants and nuclear construction projects have been examined from a perspective of coping with extreme natural events, specifically the Beyond-Design- basis External Event (BDBEE) scenarios.

In response to the Fukushima events, the US Nuclear Regulatory Commission (NRC) set up a Near Term Task Force (NTTF) which published its recommendations in July 2011[4]. These recommendations build on the longstanding defense-in-depth philosophy and NRC has started issuing Orders for the industry to implement. Of the twelve recommendations made, selected few are summarized and re-paraphrased below as they relate to the design of the reactors:

- Station blackout (SBO) mitigation capability at all operating and new reactors for design-basis and beyond-design-basis external events.
- Reliable hardened vent designs for boiling water reactors with Mark I and Mark II containments.
- Enhancing Spent Nuclear Fuel pool makeup capability and instrumentation for the monitoring the pool.
- Re-evaluate and upgrade the necessary design-basis seismic and flooding protection of Structures, Systems and Components (SSCs) for the operating reactors.
- Potential enhancements to the capability to prevent or mitigate seismically induced fires and floods.

Post-Fukushima accident lessons have led the industry to examine existing strategies and equipment related to loss of offsite site power (LOOP), coping capability for SBO, beyond-design-basis flexible mitigation strategies, hardened vents for BWR plants, and the SNF pool cooling and instrumentation.

As the NTTF recommendations are being implemented, NRC is requiring the nuclear industry to comply with the orders as they are issued. Three Orders originating from the NTTF were issued in 2012: Order EA-12-049 (Mitigating Strategies), Order EA-12-50 (Hardened Vents) and Order EA-12-51 (Spent Fuel Pool Instrumentation). In addition, the industry has begun assessing the flooding issues where relevant to the plant site and many plants have conducted comprehensive flooding walkdowns and implemented mitigating design actions.

As a worldwide overview, following the Fukushima event, several countries have put plans on hold for the new reactor construction until the safety reviews have been completed. The effect of the Fukushima event on Europe's nuclear power industry has been significant. Germany has not only reversed an earlier decision to extend the service life of the country's seventeen nuclear reactors but has now permanently shut down eight reactors and it plans to close the remaining nine in stages by 2022. In a referendum held on June 12 and June 13, 2012, Italians voted overwhelmingly against the resumption of nuclear growth in their country. Switzerland has put all plans to build new nuclear plants on hold, at least temporarily. However, other European countries (e.g. Finland, Russia, United Kingdom and Slovakia) have kept their nuclear programs unchanged.

In Asia, China, Korea, and India are expected to continue with their nuclear expansion because of the limited fuel options for energy production and a substantial need for the energy now and even greater need projected for the future. In fact, about 50% of future nuclear construction, through 2035, will come from China and India. China has more than 25 reactors currently under construction; another 34 more were also approved by the government, even though following the Fukushima accident, the government did order a safety review before proceeding further.

It is clear that Fukushima events have led to a re-thinking of role of nuclear power in several countries and some of them may decide not to pursue new build further or may even plan to phase out their nuclear power programs. However, in the longer-term, the nuclear energy can be expected to continue to play an important role in the world's energy supply.

PAST, PRESENT AND FUTURE OF REACTOR DECOMMISSIONING

Decommissioning of Nuclear Power Plants

Ample experience has already been accumulated in the decommissioning field and 102 commercial power reactors and 46 experimental or prototype reactors have been decommissioned worldwide, in addition to over 250 research reactors. The decommissioning options include: immediate decommissioning after shutdown (DECON), Safe enclosure for deferred dismantling (SAFSTOR), and entombment (ENTOMB).

The license termination process requirements in the United States are well established and substantial guidance and technical documents are available from the NRC. The requirements for the release of the decommissioned site are contained in 10 CFR 20 Subpart E (10 CFR 20.1401-1406) and guidance for decommissioning is available in NUREG-1757, NUREG-1700, NUREG 1575, NUREG-1575 Supplement 1, and RG 1.184.

Status-At-a-Glance for Reactor Decommissioning in the U.S.

The US reactor decommissioning projects have used either DECON or SAFSTOR option, with a more recent trend shifting towards SAFSTOR. Commercial reactor decommissioning is carried out under NRC jurisdiction and considerable experience has already been gained.

Table 1 has been created from information available from the NRC as well as the industry announcements related to recent plant shutdowns. It provides a snapshot of the decommissioning status of the reactors and the options selected for decommissioning, along with the information related to the presence of Independent Spent Fuel Storage Installation (ISFSI) at the site.

Table 1 Status-At-a-Glance for Commercial Reactor Decommissioning

License Terminated No Dry Storage at Site	Decommissioning Complete ISFSI at Site	Under Decommissioning DECON	Under Decommissioning SAFSTOR
Pathfinder Saxton Shoreham	Big Rock Point Fort St. Vrain Connecticut Yankee (Haddam Neck) Main Yankee Trojan Yankee Rowe Rancho Seco [Note 1] ([Note 1]complete except on-site waste storage)	Humboldt Bay LaCrosse Zion 1 Zion 2	Dresden 1 Fermi 1 GE VBWR Indian Point 1 Millstone 1 N.S. Savannah Peach Bottom 1 San Onofre (SONGS) 1 Three Mile Island 2 Recent Additions Crystal River 3 Kewaunee
		No Decision Yet SONGS 2 and 3 Vermont Yankee [Note 2] ([Note 2] closing in 2014; likely SAFSTOR)	

Note: Table 1 does not include some decommissioned demonstration reactors (e.g. Elk River, CVTR, and Piqua).

The cost of decommissioning of a commercial power reactor can range from $400 million to $1 billion depending on the size of the facility, location, access to disposal for radioactive waste, state requirements and other factors. For a full size commercial reactor the decommissioning costs are near the top end. Among the most recent reactors entering decommissioning, the combined cost for the decommissioning of SONGS Units 2 and 3 is estimated at $4 billion.

It is because of this type of high costs that many utilities would rather choose the SAFSTOR option than dismantle it immediately. While there are benefits in terms reduction in risk from the radioactivity decay, the primary driving factors are economic.

Cost of Staying in Operation for Aging Reactors

As of 2013, of the US fleet of 100 operating reactors, 20 reactors are over 40 years old; 42 reactors are between 30 to 39 years old; 37 reactors are 20 to29 years old; and 1 reactor, the youngest in the fleet at the present is 17 years old. Thus, 62 reactors in the fleet are >30 years old. Two of the oldest operating reactors are Oyster Creek and Nine Mile Point 1which entered commercial operation at the end of 1969. Watts Bar 1 is the last unit that started operation in 1996. Many of these reactors have obtained license extensions for another 20 years of operation. While the reactors continue to perform safely, the aging management issues are becoming more obvious and more costly.

Aging issues relate not only to the mechanical systems but also to the structures and are a high priority for the regulators and the industry. Refurbishment, retrofitting and upgrading nuclear reactors is expensive. Even for planned/scheduled replacements, major components are expensive to replace; for example, reactor head replacement at approximately $100 million. Some utilities may be spending up to $1 billion per plant to support the 20-year license extension for the plant.

Examples of high cost refurbishment (and where additional problems arose) include the steam generators replacement at Crystal River plant where (due to other problems) cost estimates ranged between $900 million and $1.3 billion. Duke Energy, the new owner of the plant (when it took over Progress Energy) eventually decided to shut down the facility. At the SONGS Units 2 and 3, steam generator replacements cost $780 million in 2010. However, within two years, significant damage was detected in steam-generator tubes and the leakage of radioactively contaminated water. By January 2012, the owner utility decided to shut down the units. At Vermont Yankee, leakage of tritium was attributed to the deteriorating underground pipes and the repair cost was estimated to be $700 million. At the David-Besse station where reactor pressure vessel (RPV) head degradation was identified in 2002, it was estimated earlier that RPV head replacement and the replacement power during the two year shutdown cost over $600 million, even though updated figures have not been available.

Projections of Reactor Decommissioning – Plausible Scenario

The current status on the number of US reactor shutdowns by the year is shown in Figure 5. From 1998 until 2013 there were no reactor shutdowns. During the past decade prior to the Fukushima event in 2011, things were quite optimistic for the future of nuclear power industry and there were significant plans for the new build. However, as mentioned earlier, Fukushima changed that optimistic outlook. Combined with the new trend in electricity generation sources and the changed economics, new plant retirements are on the horizon. The year 2013 data in Table 5 captures what is likely to become a trend in the future. As utilities make decisions on the economic viability of continued operation of the aging reactors, more are expected to shutdown and enter the decommissioning phase. In turn, the decommissioning industry will expand.

To get a perspective of potential future landscape in decommissioning, Figure 6 has been generated based on the actual shutdown data so far and a projected plausible scenario. The data is plotted in five year intervals. The plausible scenario is built on a number of assumptions and is based on the license expiration data including the license extensions already granted by the NRC.

Most reactors were originally granted licenses to operate for 40 years and most have received or applied for a 20-year extension. A total of 72 extensions had been granted by the NRC so far. This number includes Kewaunee and Crystal River, which have now been shut down, and Oyster Creek, which has announced that it will shutdown 10 year earlier than the extended license expiration. Several applications for license extension are pending with NRC. However, approximately half of the country's fleet of commercial power reactors is over 30 years old. Of the BWR reactors, 23 are the Mark 1 (similar to Fukushima reactors) and most are nearly 40 years old. While these operating reactors continue to perform safely, the aging management issues for the older reactors are prompting some utilities to re-examine the economic cost benefits of refurbishment and replacements of major components to keep them operational or decommission them.

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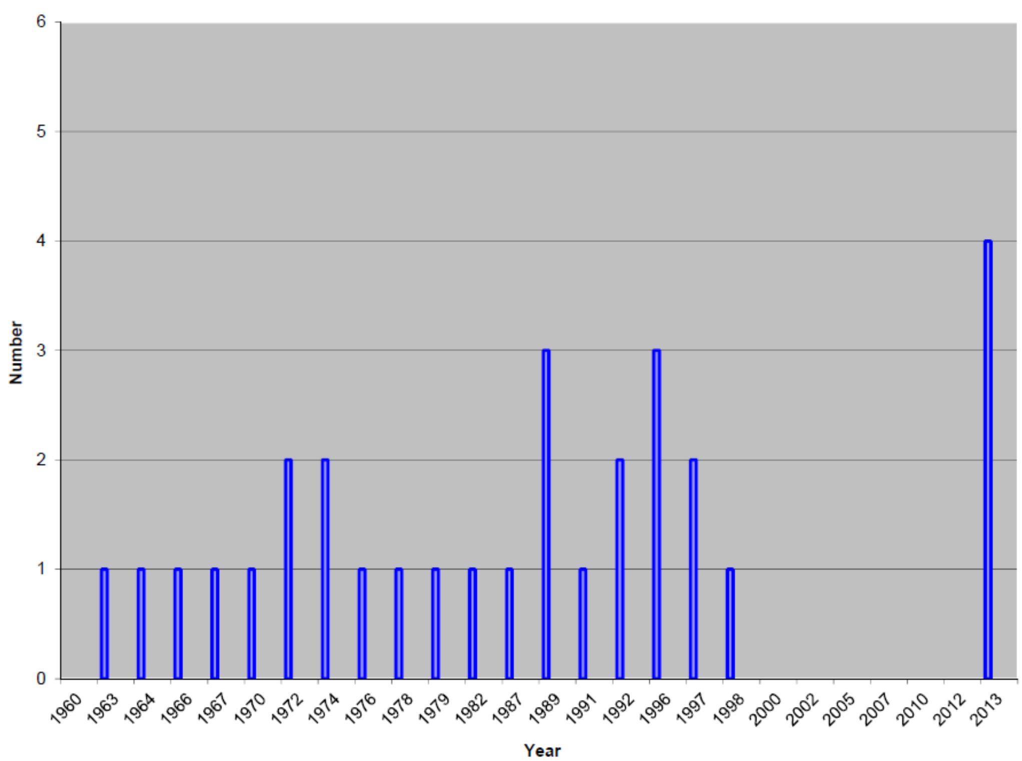

Figure 5: Reactor Shutdowns in the US by Year

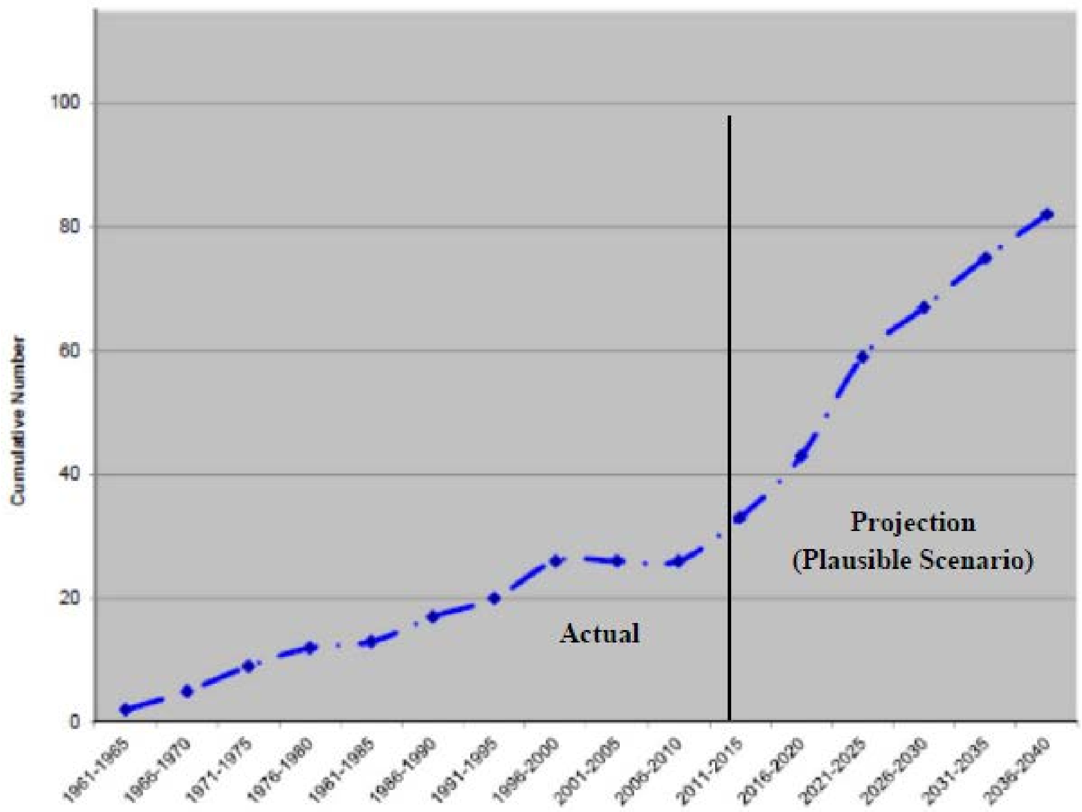

Figure 6: Cumulative Reactor Shutdowns in one Postulated Scenario

Of the 100 reactors operating at the present, 28 are operating with the original license and 72 have received license extensions of which ten are already operating in their extended license period.
However, from a decommissioning perspective, what is more relevant is the age of the reactors and the ability and willingness of the utilities to upgrade the large components to stay operational.

As of the end of 2013, a total of 20 reactors were over 40 years old. This number will be supplemented with additional 14 reactors at the end of 2014. For the purpose of this assessment, the 20 older reactors are assumed to enter decommissioning in the next 10 years and assumed to be all decommissioned by 2025; the data are distributed between 2015 and 2025. From the list of reactors where licenses have already been extended by the NRC for additional 20 years, the end of licensing periods up to 2040 is considered and the number of reactors is distributed in 5-year intervals (excluding the 20 older reactors already distributed). To acknowledge the possibility of further license renewal it is assumed that half of the reactors with license expiration after 2020 will continue operation (except for the older reactors mentioned above). The data (cumulative number of decommissioning reactors) are adjusted accordingly from 2020 to 2040. The projections are limited up to the year 2040. Note that an additional 21 reactors have extended licenses that go beyond 2040 (the longest one ends in 2049). Again, it is possible that about half of these reactors may have further license extensions. However, these are not represented in the given scenario as the scenario is limited to year 2040. Any additional new builds are also excluded from the data as they will not be entering decommissioning prior to 2040. Note that the cumulative number includes the reactors that have already been decommissioned so far.

Based on the assumptions and limitations described above, Figure 6 shows a sharp rise in the cumulative total number of reactors within the decommissioning scene (decommissioned, in decommissioning, and those expected to enter decommissioning).

Unintended Consequence of SAFSTOR Option

It is well understood that decommissioning a nuclear reactor is costly and difficult. Even under the immediate dismantlement option (DECON), decommissioning projects can take 10 or more years to complete. Regulatory challenges are also significant, especially in those cases where states have taken up a prominent role in the decommissioning process and the outcome.

As stated earlier and shown in Figure 6, a sharp upswing in the shutdown reactors is plausible. Normally, in the past experience with decommissioned power reactors, there has been a nearly equal split between the DECON and SAFSTOR options. Specifically, the SAFSTOR option has advantages for sites where multiple units are present and where one unit enters decommissioning and other units remain operational. SAFSTOR, as deferred decommissioning, allows radioactive materials to decay to lower radioactivity levels thus reducing both the radiological risk and the disposal issues. This is especially significant in special circumstances such as the TMI Unit 2, where the accident had taken place.

The goal of decommissioning is the safe removal of the facility from use, decontaminate and decommission the equipment and release the site under a regulatory process. A number of reactors have undergone this process and the facility sites (except for ISFSIs) have been released. For most part this is they preferred path. The technologies for decontamination, removal of the major components, removal of radioactive waste, as well as, for radiological survey and release of a site are well established. Funds for decommissioning are generally collected throughout the operating lifetime of the plant as a ratepayer levy on a kWh basis. While in some cases availability of adequate funds may be an issue, typically enough funds have been collected by most reactors for decommissioning to take place.
However, a new trend also appears to be taking hold that as reactors are shutdown for economic or other reasons, the method of choice for the recently retired reactors is the SAFSTOR option. While SAFSTOR has its role and advantages as mentioned earlier, there are clear advantages for immediate dismantlement and decommissioning in most cases. The industry has substantial experience with large scale decommissioning including decommissioning of a dozen commercial power reactors and numerous small scale facilities. The industry has also substantial experience in building dry storage facilities for longer term storing of spent fuel while the national policy debate on the issue drags on.

As companies make decision to choose SAFSTOR over DECON and let the plant sit for 50 or more years, some states are weighing in on the decommissioning path chosen. As an example, the New York state administration has maintained that they will work to decommission nuclear reactors at Indian Point (rather than allow Entergy, the operator of the plant to use the deferred decommissioning option). The licenses for Indian Point Unit 1 and 2 are set to expire in 2013 and 2015 and it is estimated that the cost of decommissioning both units will be approximately $1.5 billion.

Another significant concern related to SAFSTOR that is gaining public attention is that shutdown reactors could dot the landscape, much the same way as the ISFSIs are across the country due to a lack of disposal pathway for the spent nuclear fuel. In addition to the pressure form the states as mentioned earlier, the regulatory guidance at the federal level may evolve in future to address this issue.

Used Nuclear Fuel Issue and its Impact on Nuclear Power and Reactor Decommissioning

What to do with the Used Nuclear Fuel (also called SNF) has stymied the national decision making for decades. Its impact has been a long term impasse that has resulted in the decommissioned reactors still having onsite storage of SNF to deal with.

The operating reactors at many sites have little pool storage capacity left and have resorted to dry storage facilities constructed at the reactor sites. Dating back to the Nuclear Waste Policy Act (NWPA) of 1982 [5], the DOE is responsible for taking SNF from the US commercial power reactors and the utilities have continued to contribute money to the Nuclear Waste Fund. Note that while some countries have regarded SNF as a resource and proceeded with the reprocessing programs, the US national policy has been to treat SNF as waste. DOE was initially set to begin accepting commercial SNF by January 31, 1998. However, a series of delays due to legal challenges, concerns over how to transport nuclear waste, as well as the political pressures have kept a site from being developed. The NWPA as amended in 1987, provided only for the evaluation and licensing of a single repository site at Yucca Mountain, Nevada. The DOE has been studying the site located near the former Nevada Test Site for almost three decades. After an expenditure of approximately $13 billion on the project and pursuing a NRC license for the site in 2008, the DOE started backtracking in 2009 with a changed direction from the new Administration. A motion to withdraw the license application was filed with NRC in 2010. The project funding was zeroed out in the 2011 DOE budget cycle.

Litigation against the DOE from the nuclear utilities continues and already substantial judgments have been granted by the courts as compensation to utilities for the management of the SNF.

The industry’s response to the lack of progress at the national level has been the design, fabrication, and installation of dry storage cask facilities at reactor sites. ISFSI locations dot the map as 69 such facilities are already located in 34 states and new ones are expected to be added.

The issue is significant to the future of nuclear power as well as the status of decommissioned sites. The commercial US nuclear power plants generate 2,000 to 2,400 t of SNF annually and the stored inventory of approximately 70,000 t is about one third in dry storage and about two thirds in pool storage. Projected SNF quantity in storage by 2020 is expected to grow to about 88,000 t. The SNF is also stored at several decommissioned reactor sites in the US in dry storage systems: Main Yankee, Connecticut Yankee (Haddam Neck), Trojan, Rancho Seco, Yankee Rowe, Big Rock Point, Humboldt Bay, and La Crosse. In total this quantity is about 1,756 t. In addition, the Zion station, which is currently in decommissioning, has SNF stored in the pool. Once this SNF is transferred to dry storage, it will add 1,019 t to the total; bringing the overall total to about 2,813 t.

At those sites where decommissioning is complete, the ISFSIs are the only facilities left at the site i.e., stand-alone facilities, a legacy of the stalemate on the SNF disposition issue. The stored SNF will remain at the sites until removal by the DOE to a repository or a central storage site.

The latest national attempt by the government has been to set up a Ribbon Commission on America's Nuclear Future (BRC) in March 2010 to provide a comprehensive review of policies for managing the backend of the nuclear fuel cycle. The BRC issued its report to the Secretary of Energy in January 2012 [6]. Among the several "key elements" contained in the 2012 BRC report are the new, consent-based approach to siting, a new federal organization dedicated solely to implementing the waste management program, and development of one or more consolidated storage facilities for interim storage of SNF. Related to the latter, the DOE's Office of Nuclear Energy has been conducting research under the Used Nuclear Fuel Disposition Program since 2010 and the program has begun laying the groundwork [7-8] for evaluating consolidated storage concepts.

With Yucca Mountain project stopped, the hopes have faded that SNF will find a path to geologic disposal any time soon. However, in DOE's quest for a centralized SNF storage facility the decommissioned sites are expected to be at the top of the list for removal of the SNF, if such a facility is built.

CONCLUSIONS

This paper has covered extensive ground including energy demand, changing energy generation economics and its impact on nuclear power and reactor shutdowns, the Fukushima accident and the impact of follow up actions, status and issues in reactor decommissioning including used fuel storage, and the current trends and projections in reactor decommissioning. The common thread for all topics and issues examined is their impact on the nuclear power and reactor decommissioning. Important conclusions can be summarized as below.

Changing energy economics is impacting the future of nuclear power in the United States. Natural gas is becoming the fuel of choice for many electric utilities with a diversified generation portfolios. Nuclear industry is re-examining the economic viability of reactors, especially the older reactors.

Post-Fukushima regulatory actions require nuclear power industry to make provisions and changes for Beyond-Design-Basis External Events. Among other factors, for the older reactors, it can be the tipping point on their economic competitiveness with other sources of power.

Reactor decommissioning scene is changing and after a period of about fifteen years, several reactors were either shutdown or announced their early shutdown in the past two years. Based on an analysis of the reactors licenses including the renewed licenses and the age of the reactors, projections for a plausible scenario show a sharp upswing in the cumulative total reactors in the decommissioning phase in the next twenty five years. However, the current industry shift towards deferred decommissioning where the plant could sit in shutdown state for several decades may not be sustainable in the long run due to state intervention, future regulatory actions, and public opposition.

Lack of a disposal path for used nuclear fuel impacts both the operating reactors and the decommissioned sites. Closure of the Yucca Mountain project is a major setback in this regard. Based on a part of the BRC recommendations, the DOE has been examining concepts for centralized storage facility development for the used nuclear fuel.

Nuclear power in the United States is at a critical juncture due to a shift in the energy market conditions and due to a number of recent events. In this environment, more reactors are expected exit the energy production for economic reasons and enter the decommissioning phase.

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